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ABSTRACT

The electrical resistivity and magnetic susceptibility of the cubic intermetallic compounds UIr_2 ($MgCu_2$-type) and UIr_3 (ordered, $AuCu_3$-type) have been measured between 2-300K. The susceptibility of UIr_3 is temperature independent and substantially lower than that of isoelectronic URh_3 being 0.57 vs 0.97 x 10^{-3} emu/mole at room temperature. The susceptibility of UIr_2 is very weakly temperature dependent above 100K, and has a value of 1.18 x 10^{-3} emu/mole at room temperature. The electrical resistivities of both compounds follow power law dependences at low temperatures, of the form $\rho-\rho_o = AT^n$, with n = 1.9 for UIr_2 and n = 3.7 for UIr_3. These results indicate that UIr_2 may be a spin fluctuation compound, while UIr_3 behaves as a simple transition metal compound, with even less d-f character than URh_3 (n = 3.0). The specific heat of UIr_2 was measured between 1-4K and may be fit to $C = \gamma T + \beta T^3$, with a large value of γ, 62.5 mJ/(mole-K^2). which is consistent with a narrow 5f band at the Fermi level. The lack of any magnetic phenomena in UIr_3 is explained by the hybridization of the 5f electrons into f-d bands, which mostly lie below the Fermi level.

INTRODUCTION

In view of the large variety of magnetic phenomena found in metallic actinides, it is desirable to systematically study actinide systems to help unravel the physics underlying the various phenomena. This paper presents the results of a study of the electrical resistivity and magnetic susceptibility of UIr_2 and UIr_3 between approximately 2 and 300K. Specific heat measurements were also made on UIr_2 between 1.5 and 4.2K. UIr_2 forms peritectically in the $MgCu_2$-type cubic Laves phase, and UIr_3 crystallizes congruently in the ordered $AuCu_3$ structure. The measurements on UIr_3 are of special interest since they may be compared with preliminary deHaas-van Alphen (dHvA) results for this compound,[1] and with the fairly complete dHvA and band structure results for isoelectronic URh_3.[2]

EXPERIMENTAL

Samples were prepared by arc-melting the constituents, followed by electrolytic machining where necessary. The correct single phase structures were verified by x-ray diffraction methods. The UIr_2 was annealed at 1040°C for ten days. Experimental techniques used in this work have been described previously.[3,4,5]

RESULTS

The temperature dependence of the susceptibility is given in Fig. 1 for both compounds. Although both sets of data are essentially temperature-independent, there is a slight maximum in the UIr_2 data at 60 ± 2K. The room temperature value for UIr_3 (0.570×10^{-3} emu/mole) is about 0.6 as large as the value for URh_3 (0.973×10^{-3} emu/mole),[6] and the UIr_2 value is slightly higher (1.176×10^{-3} emu/mole) than the URh_3 value.

The low temperature resistivities are plotted as $\log(\rho-\rho_o)$ vs log T in Fig. 2. Both sets of data may be represented by $\rho-\rho_o = AT^n$, with n = 1.9 for UIr_2 and n = 3.7 for UIr_3. The latter value is to be compared to n = 3.0 for isoelectronic URh_3.[6] The values of $\rho_{300}-\rho_o$ are 122 μΩcm for UIr_2 and 34 μΩcm for UIr_3 (vs 54 for URh_3). There is a small bump in the ρ-T curve for UIr_2 with a height of only 0.5 out of 60 μΩcm, and centered at 57K, with a width of 2-3K.

The specific heat data for UIr_2 are well represented by $C = \gamma T + \beta T^3$, with $\gamma = 62.5 \pm 1.0$ mJ/(mole-K^2) and $\beta = 0.50 \pm 0.03$ mJ/(mole-K^4), corresponding to a Debye temperature, $\Theta_D = 227 \pm 5$K.

DISCUSSION

The higher power law exponent for the UIr_3 resistivity data versus URh_3 indicates significant s-s or p-p scattering in addition to s-d scattering. The much smaller $\rho_{300}-\rho_o$ for UIr_3 vs URh_3 is in agreement with this proposal. This conclusion is supported further by the dHvA data, which show more s-like orbits than are found in URh_3. The tentative band structure for UIr_3 (based strongly on the URh_3 results) explains the lack of magnetism in UIr_3, also, since the f-electrons are all strongly hybridized into f-d bands, which mostly lie well below the Fermi level.

The small maximum in the UIr_2 susceptibility accompanied by the small resistivity anomaly, is probably not associated with a magnetic transition. Most likely it is due to a slight cubic to tetragonal distortion as is found in other actinide cubic Laves phase compounds with transition metals.[7] The lack of magnetic ordering is

supported further by an almost trivial temperature dependent susceptibility between 150-300K. Additional measurements on UIr_2 in the temperature region near 60K are necessary to determine the cause of the susceptibility maximum. Among these are x-ray diffraction and specific heat.

However, the low-temperature T^2 resistivity for UIr_2 indicates a magnetic phenomenon. By analogy with many other actinide compounds, it is likely that UIr_2 is a spin fluctuation compound.[8,9] The slope of the T^2 regime yields a spin fluctuation temperature, T_{sf}, of 200K, while the limit of the T^2 regime only yields $T_{sf} \sim 60K$. However, for a T_{sf} this large an upper limit to the T^2 dependence becomes hard to separate from the total resistivity. We point out that since the spin fluctuation contribution to the specific heat, $T^3 \ln T/T_{sf}$, goes to $T = 0$ as T^3, a spin fluctuation contribution would be inseparable from the lattice contribution for $T << T_{sf}$. For UAl_2, a $T_{sf} = 23K$ permitted the observation of a low temperature upturn in C/T due to the spin fluctuation term.[9] The large value for γ is in agreement with a spin fluctuation model which requires a narrow 5f band at or near the Fermi level. An estimate of the exchange enhancement factor, $S = \chi/\gamma$, of 2.3 is obtained from the experimental data. This does not allow for the unknown electron-phonon enhancement of the electronic specific heat or orbital contribution to the susceptibility.

One mechanism which has been widely used to explain the lack of magnetism in many actinide compounds is broadening due to 5f-5f direct overlap as a consequence of relatively short interactinide distances.[10] This mechanism is certainly operable in the cubic Laves phase structure where the U-U distance in UIr_2, for example, is only 3.25A. In the case of $AuCu_3$-type compounds, the larger U-U distance, e.g., 4.023A for UIr_3, should lead to local moment behavior if 5f-5f overlap is the only mechanism for broadening. However, in some actinide-transition metal compounds additional broadening occurs via 5f-6d hybridization which is favorable in this structure, and is stronger than 5f-5f overlap. Hence, there may be no magnetic behavior. By adding more 5f electrons as in going from URh_3 to $PuRh_3$, one may obtain a situation with some unhybridized, localized 5f electrons. Thus, $PuRh_3$ is a good example of 5f local moment behavior.[6,11]

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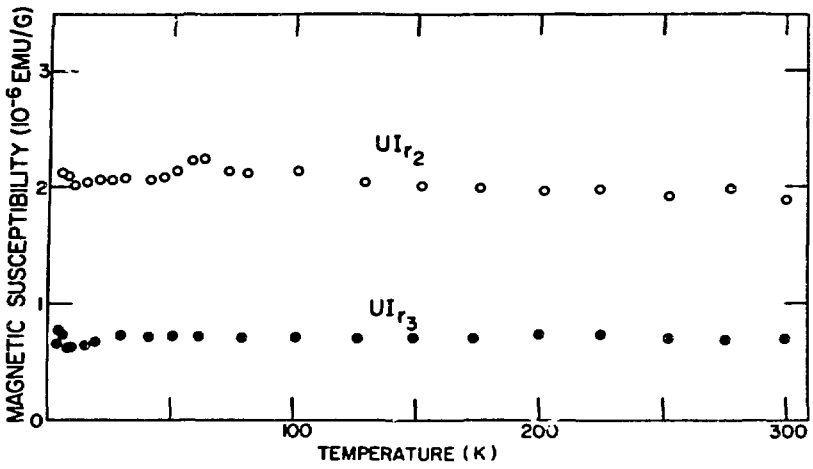

Fig. 1. Magnetic susceptibility vs temperature for UIr_2 and UIr_3. (MSD Neg. #61891.)

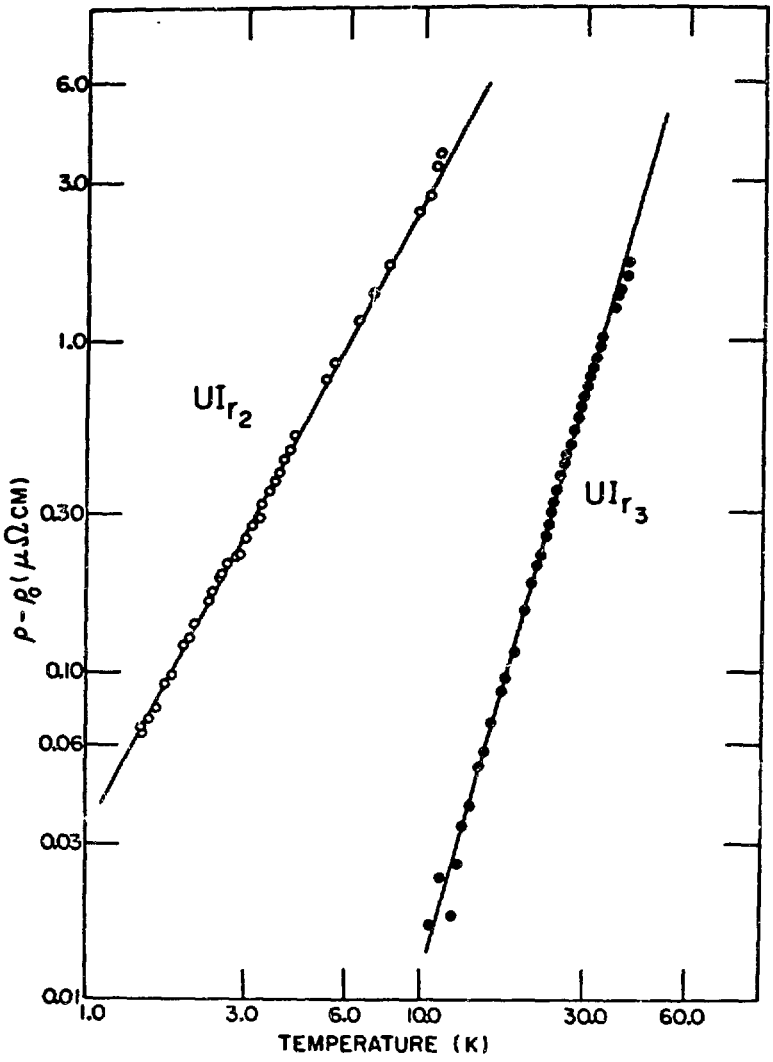

Fig. 2. Log ($\rho-\rho_o$) vs Log T for UIr_2 and UIr_3 at low temperatures. (MSD Neg. #61890.)